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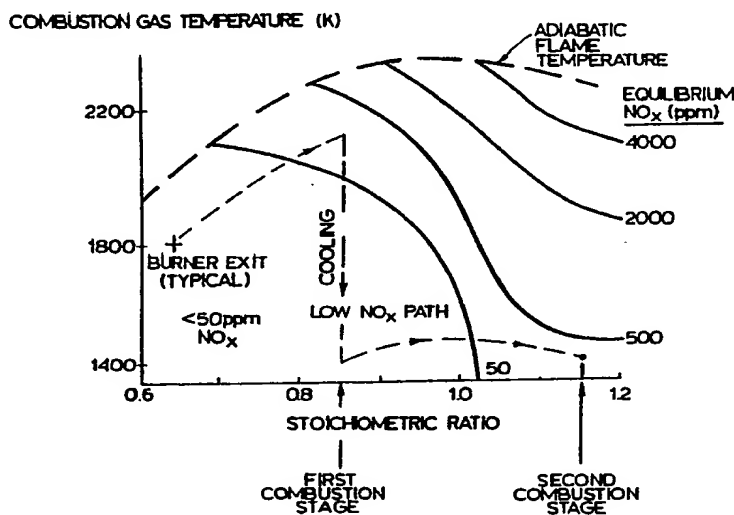
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## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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(21) International Application Number: PCT/CA91/00004 (22) International Filing Date: 8 January 1991 (08.01.91) (30) Priority data: 461,939 8 January 1990 (08.01.90) US (71) Applicant: TRANSALTA RESOURCES INVESTMENT CORPORATION [CA/CA]; 110-12th Avenue S.W., Box 1900, Calgary, Alberta T2P 2M1 (CA). (72) Inventor: DYKEMA, Owen, W. ; 23429 Welby Way, Canoga Park, CA 91307 (US). (74) Agents: NASSIF, Omar, A. et al.; McCarthy Tetrault, P.O. Box 48, Toronto-Dominion Bank Tower, Toronto, Ontario M5K 1E6 (CA).		(81) Designated States: AT (European patent), AU, BB, BE (European patent), BF (OAPI patent), BG, BJ (OAPI patent), BR, CA, CF (OAPI patent), CG (OAPI patent), CH (European patent), CM (OAPI patent), DE (European patent), DK (European patent), ES (European patent), FI, FR (European patent), GA (OAPI patent), GB (European patent), GR (European patent), HU, IT (European patent), JP, KP, KR, LK, LU (European patent), MC, MG, ML (OAPI patent), MR (OAPI patent), MW, NL (European patent), NO, RO, SD, SE (European patent), SN (OAPI patent), SU, TD (OAPI patent), TG (OAPI patent).  <b>Published</b> <i>With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>	

## (54) Title: COMBUSTION PROCESS



## (57) Abstract

A combustion process for nitrogen- or for sulphur- and nitrogen bearing fuels wherein fuel combustion is divided, by staged oxygen (preferably in the form of air) injection, into at least two combustion zones. The first combustion zone involves providing fuel-rich stoichiometric conditions under which nitrogen chemically bound in the fuel (i.e. fuel-bound nitrogen) is substantially converted to molecular nitrogen. The second (final) combustion zone comprises at least two stages. In the first stage of the final combustion zone, combustion products from the first combustion zone are further combusted under a condition of fuel-rich stoichiometry, preferably at an oxygen/fuel stoichiometric ratio of from about 0.80 to about 1.0 and at a temperature of less than about 2200 K (1927 C, 3500 F). In the second stage of the final combustion zone, combustion products from the first stage are combusted at an oxygen/fuel stoichiometric ratio of greater than about 1.0 and at a temperature of less than about 1500 K (1227 C, 2240 F). In this final zone, fuel combustion is completed while formation of new thermal NO<sub>x</sub> is substantially prevented. Thus, the process may be used to reduce emissions of undesirable nitrogenous compounds (e.g. NO<sub>x</sub>) which would ordinarily be formed during completion of fuel combustion. The process is particularly appropriate for use with the fuel-rich gases from a burner designed to control air pollutants arising from sulphur and nitrogen in the fuel.

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-1-

COMBUSTION PROCESSTECHNICAL FIELD

5 The present invention relates to a process for the combustion of a nitrogen-bearing or a sulphur- and nitrogen-bearing fuel. More particularly, the present invention relates to a combustion process for such a fuel whereby the emission of undesirable gaseous nitrogenous compounds (e.g.  $\text{NO}_x$ ) is minimized.

10 BACKGROUND ART

It is known that during conventional combustion of fossil fuels, the nitrogen and sulphur chemically bound in those fuels can be oxidized to  $\text{NO}_x$  and  $\text{SO}_x$ , respectively. In addition,  $\text{NO}_x$  can be formed by high temperature oxidation of nitrogen in the combustion air.  $\text{NO}_x$  derived from the first of these mechanisms (i.e. from fuel-bound nitrogen) is referred to as "fuel  $\text{NO}_x$ " while that derived from the second of these mechanisms (i.e. from nitrogen in the combustion air) is referred to as "thermal  $\text{NO}_x$ ". A great deal effort in the prior art has been devoted to addressing prevention of the formation of fuel  $\text{NO}_x$  during combustion of fossil fuels in excess air. If these acid gases,  $\text{NO}_x$  and  $\text{SO}_x$ , are released to the atmosphere, they can be absorbed in atmospheric moisture and thereafter precipitate to earth as acid rain.

United States patents 4,427,362 (Dykema) and 4,523,532 (Moriarty et al), the contents of both of which are incorporated herein by reference, teach a combustion process for substantially reducing emissions of fuel  $\text{NO}_x$  and of combined fuel  $\text{NO}_x$  and  $\text{SO}_x$ , respectively, during combustion. Both of these patents teach a combustion process wherein particular oxygen/fuel stoichiometric ratios and temperatures are provided to facilitate conversion of substantially all fuel-bound nitrogen to harmless molecular nitrogen ( $\text{N}_2$ ). Moreover, Moriarty et al teach an additional (first) combustion zone to provide

**SUBSTITUTE SHEET**

-2-

control of  $\text{SO}_x$  emissions in addition to the control of fuel  $\text{NO}_x$  emissions taught by Dykema. Typically, these air pollutants are simultaneously controlled during combustion in a burner called the low  $\text{NO}_x/\text{SO}_x$  burner.

5                    Thus, both Dykema and Moriarty et al teach combustion processes which result in very low levels of fuel  $\text{NO}_x$  leaving the low  $\text{NO}_x/\text{SO}_x$  burner. However, the low  $\text{NO}_x/\text{SO}_x$  burner is not designed to fully complete carbon and hydrogen combustion within the burner, but rather only to the level  
10                    necessary to provide the desired air pollution control. As a result, combustion products leaving the burner and, thereafter, typically entering a boiler, are still the products of fuel-rich combustion. The gases contain high concentrations of carbon monoxide and hydrogen, and the entrained particulate still contains some unburned carbon. All of these fuel constituents must be oxidized, to their  
15                    lowest energy state, to maximize heat release.

15                    Therefore, at least one subsequent combustion zone, involving high temperatures and/or excess air, is required to complete hydrocarbon combustion. Both Dykema and Moriarty et al teach injecting all of the remaining excess air immediately at the end of the process (i.e. at the exit of  
20                    the low  $\text{NO}_x/\text{SO}_x$  burner). This results in a combination of both high temperatures and excess air in the final combustion zone. The combustible gases and solids can be conveniently burned to completion in this zone. However, there also exists the likelihood that appreciable concentrations of thermal  $\text{NO}_x$  may be generated in this final combustion zone.

25                    Thus, it appears that the prior art processes are deficient in that they do not provide a means of minimizing or substantially eliminating the production of "new", thermal  $\text{NO}_x$  as final fuel combustion is being completed.

**SUBSTITUTE SHEET**

-3-

DISCLOSURE OF THE INVENTION

It is an object of the present invention to provide a novel fuel combustion process whereby, upon completion of combustion, the emission of  $\text{NO}_x$ , particularly thermal  $\text{NO}_x$ , is reduced or substantially eliminated.

5

Accordingly, in its broadest aspect, the present invention provides a combustion process for nitrogen- or for sulphur- and nitrogen-bearing fuels wherein fuel combustion is divided, by staged oxygen (preferably in the form of air) injection, into at least two combustion zones. The first combustion zone involves providing fuel-rich stoichiometric conditions under which nitrogen chemically bound in the fuel (i.e. fuel-bound nitrogen) is substantially converted to molecular nitrogen. The second (final) combustion zone comprises at least two stages.

15

In the first stage of the final combustion zone, combustion products from the first combustion zone are further combusted under a condition of fuel-rich stoichiometry, preferably at an oxygen-fuel stoichiometric ratio of from about 0.80 to about 1.0 and at a temperature of less than about 2200 K. In the second stage of the final combustion zone, combustion products from the first stage are combusted at an oxygen/fuel stoichiometric ratio of greater than about 1.0 and at a temperature of less than about 1500 K. In this zone, fuel combustion is completed while formation of new, thermal  $\text{NO}_x$  is substantially prevented.

25

It has been discovered that the provision of this two-stage final combustion zone can also provide significant advantages in ultimate  $\text{NO}_x$  control in many combustion systems. Thus, it is believed that the two-stage final combustion zone of the present invention may also be utilized with many of the prior art  $\text{NO}_x$  control combustion processes which use a more

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conventional single stage (excess air) combustion zone as hereinbefore described.

#### BRIEF DESCRIPTION OF THE DRAWING

5                   Embodiments of the present invention will be described with reference to the attached Figure, in which there is illustrated a plot of combustion temperature versus oxygen/fuel stoichiometric ratio, including a number of lines of constant equilibrium  $\text{NO}_x$ .

#### 10           BEST MODE FOR CARRYING OUT THE INVENTION

                  As used throughout this specification the term "fuel-rich combustion products" refers to combustion gases comprising a major concentration of a reduced compound such as one or more of carbon monoxide, hydrogen,  $\text{NH}_3$ ,  $\text{HCN}$ ,  $\text{H}_2\text{S}$  and unburned gaseous hydrocarbons, along with  
15           more conventional oxides of said compounds. Moreover, the term "fuel-rich stoichiometry" refers to oxygen/fuel stoichiometric ratios less than 1.0.

                  In a preferred embodiment of the present invention, there is provided a combustion process for a nitrogen-bearing fuel comprising the steps  
20           of:

- (a) introducing the fuel into a first combustion zone;
- (b) combusting the fuel in the first combustion zone under a condition of fuel-rich stoichiometry and at a temperature whereby fuel-rich combustion products are produced and undesirable nitrogenous compounds are  
25           reduced to low levels;
- (c) passing these fuel-rich combustion products into a two-stage final combustion zone;
- (d) combusting the combustion products in the first stage of the final combustion zone under a condition of fuel-rich stoichiometry and at a  
30           temperature of less than about 2200 K; and

# SUBSTITUTE SHEET



-5-

(e) thereafter, combusting the combustion products from the first stage in the second stage of the final combustion zone at an oxygen/fuel stoichiometric ratio of greater than about 1.0 and at a temperature of less than about 1500 K.

5

In this embodiment of the present invention, the first combustion zone is essentially a fuel  $\text{NO}_x$  control zone. It is preferred to add to this first combustion zone a finely dispersed particulate material which enhances conversion of undesirable nitrogenous compounds (e.g.  $\text{NO}_x$ ,  $\text{NH}_3$  and  $\text{HCN}$ ) to harmless molecular nitrogen. Non-limiting examples of suitable particulate materials include calcium sulphide, calcium oxide, iron sulphide, iron oxide and mixtures thereof. The condition of fuel-rich stoichiometry in the first combustion zone preferably comprises an oxygen/fuel stoichiometric ratio of from about 0.45 to about 0.80, more preferably from about 0.55 to about 0.70.

10

15 The temperature in the first combustion zone is preferably in the range of from about 1500 K to about 1800 K.

In another embodiment, the present invention provides a combustion process for a sulphur- and nitrogen-bearing fuel comprising the steps of:

20

- (a) introducing the fuel into a first combustion zone;
- (b) combusting the fuel in the presence of a sulphur-capture compound in the first combustion zone under a condition of fuel-rich stoichiometry and at a temperature whereby a combustion mixture is produced including fuel-rich gases, solid sulphur-bearing flyash and slag;
- 25 (c) passing the combustion mixture to a second combustion zone;
- (d) combusting the mixture in the second combustion zone under a condition of fuel-rich stoichiometry and at a temperature whereby fuel-rich combustion products are produced, such that the undesirable nitrogenous compound level in the combustion products is reduced to a low level;
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**SUBSTITUTE SHEET**

-6-

(e) passing the combustion products into a two-stage final combustion zone;

(f) combusting the combustion products in the first stage of the final combustion zone under a condition of fuel-rich stoichiometry and at a temperature of less than about 2200 K; and

(g) thereafter, combusting the combustion products in the second stage of the final combustion zone at an oxygen/fuel stoichiometric ratio greater than about 1.0 and at a temperature of less than about 1500 K.

In this embodiment of the present invention, the first combustion zone is essentially a sulphur capture or  $\text{SO}_x$  control zone and the second combustion zone is essentially a fuel  $\text{NO}_x$  control zone. Preferably, the sulphur-capture compound is calcium-based, more preferably the compound is selected from the group comprising oxides, hydroxides and carbonates of calcium. The most preferred sulphur-capture compound is calcium carbonate (limestone).

Preferably, the condition of fuel-rich stoichiometry in the first combustion zone comprises an oxygen/fuel stoichiometric ratio of less than about 0.50, more preferably from about 0.25 to about 0.40. The temperature in the first combustion (i.e. sulphur capture) zone is preferably in the range of from about 1200 K to about 1600 K. Preferably, the condition of fuel-rich stoichiometry in the second combustion (i.e. fuel  $\text{NO}_x$  control) zone comprises an oxygen/fuel stoichiometric ratio of from about 0.45 to about 0.80, more preferably from about 0.55 to about 0.70. The temperature in the second combustion zone is preferably in the range of from about 1500 K to about 1800 K.

For the two embodiments discussed above, it is preferred that the condition of fuel-rich stoichiometry in the first stage of the final combustion

**SUBSTITUTE SHEET**

-7-

zone comprises an oxygen/fuel stoichiometric ratio of from about 0.80 to about 1.0.

In yet another embodiment of the present invention, there is provided a coal combustion process comprising the steps of:

- (a) introducing particulate coal into a first combustion zone;
- (b) combusting the coal in the presence of a sulphur-capture compound in the first combustion zone at an oxygen/fuel stoichiometric ratio of from about 0.25 to about 0.40 and at a temperature in the range of from about 1200 K to about 1600 K, whereby a combustion mixture is produced including fuel-rich gases, slag and solid sulphur-bearing flyash entrained in the gases;
- (c) passing the combustion mixture to a second combustion zone;
- (d) combusting the combustion mixture in the second combustion zone at an oxygen/fuel stoichiometric ratio of from about 0.55 to about 0.70 and at a temperature in the range of from about 1500 K to about 1800 K, whereby fuel-rich combustion products are produced, such that the level of undesirable nitrogenous compounds in the combustion products is reduced to a low level;
- (e) separating the slag and a major portion of the flyash from the combustion products;
- (f) passing the remaining combustion products into a two-stage final combustion zone;
- (g) combusting the remaining combustion products in the first stage of the final combustion zone at an oxygen/fuel stoichiometric ratio of from about 0.80 to about 1.0 and at a temperature of less than about 2200 K; and

(h) thereafter, combusting the combustion products from the first stage in the second stage of the final combustion zone at an oxygen/fuel

# SUBSTITUTE SHEET

-8-

stoichiometric ratio of greater than about 1.0 and at a temperature of less than about 1500 K.

5 It should be appreciated that reference to a particular "oxygen/fuel stoichiometry" as used in this specification also encompasses mixtures of air and fuel where air is used in sufficient quantity such that the amount of oxygen provided by the air meets the particular oxygen/fuel stoichiometry.

10 Throughout the specification, when reference is made to low levels of nitrogenous compounds in the combustion products entering the final combustion zone, it will be appreciated that this refers to  $\text{NO}_x$  levels preferably less than about 500 ppm, more preferably less than about 250 ppm and most preferably at about 100 ppm.

15 Generally, the present invention is suitable for use with conventional combustible fuels. Non-limiting examples of such fuels include coal, lignite, wood, tar and petroleum by-products which are solid at ambient temperatures; mixtures of two or more of these fuels may also be used. The preferred fuel for use with the present process is coal.

20 Referring now to the Figure, there is illustrated a plot of combustion temperature versus oxygen/fuel stoichiometric ratio, including a number of lines of constant equilibrium  $\text{NO}_x$ . The Figure shows that  $\text{NO}_x$  levels are very sensitive to both gas temperature and stoichiometric ratio for 25 temperatures less than about 2200 K and stoichiometric ratios less than about 1.10. For example, at a stoichiometric ratio of 0.85, the gases have to be cooled only about 12% (i.e. from about 2240 K to about 1990 K) to reduce equilibrium  $\text{NO}_x$  levels from about 500 ppm to about 50 ppm.

**SUBSTITUTE SHEET**

-9-

In the case of combusting a sulphur- and nitrogen-bearing fuel, it is preferred to remove the slag formed and a major portion of the solid sulphur-bearing flyash entrained in the combustion gases present after the second (fuel  $\text{NO}_x$  control) combustion zone. This may be achieved utilizing a suitable slag/flyash separator. When such a separator is used, approximately 6 percent of the heat of combustion of the fuel is removed from the hot gases by the water cooling circuit in the separator. This corresponds to about a 200 K cooling from adiabatic of the gases exiting the burner into the final combustion zone (typically in a boiler). Approximately half of the remaining excess oxygen may then be injected into the fuel-rich gases leaving the burner thereby raising the stoichiometric ratio of the gases entering the first stage of the final combustion zone to from about 0.8 to about 1.0. Final combustion conditions in the first stage of this zone will be such that equilibrium  $\text{NO}_x$  levels are at or near zero. During this stage, under such relatively high temperatures and at nearly stoichiometric mixture ratios, carbon monoxide, hydrogen and any unburned carbon may be substantially burned out with virtually no generation of "new", thermal  $\text{NO}_x$ . Preferably, the first stage of the final combustion zone is provided with heat transfer means to cool the gases to less than 1500 K before they enter the second stage of the final combustion zone. Final, excess oxygen is then added to facilitate substantially complete fuel burnout in the second stage.

A preferred mode of operating the final two-stage combustion zone of the present invention is shown in the Figure by the dashed line labelled "Low  $\text{NO}_x$  Path". As illustrated, the first stage of the final combustion zone encompasses an oxygen/fuel stoichiometric ratio of greater than about 0.80 and a temperature of less than about 2200 K. The second stage of the final combustion zone encompasses an oxygen/fuel stoichiometric ratio of greater than about 1.0 and a temperature of less than about 1500 K.

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**SUBSTITUTE SHEET**

-10-

An embodiment of the present invention will now be described with reference to the following Example, which should not be construed as limiting the invention.

5 A pilot-scale low  $\text{NO}_x/\text{SO}_x$  burner was provided. The burner comprised first combustion (i.e. sulphur capture) and second combustion (i.e. fuel  $\text{NO}_x$  control) zones. Combustion gases exited the burner at relatively low oxygen/fuel stoichiometric ratios and at relatively high temperatures. All of the final combustion oxygen was injected, in the form of air, into these fuel-rich  
 10 combustion gases at the burner exit. Final combustion was completed in a simulated boiler section which comprised approximately 5.2 m of externally water-cooled bare steel ducting followed by approximately 4.6 m in the first pass of a commercial waste heat boiler. The combustion gases were cooled in the bare steel ducting section to about 1200 K. The results of the experiments  
 15 are provided in Table 1. It should be appreciated that Examples 3 and 4 are of a comparative nature only and, thus, are outside the scope of the present invention.

**TABLE 1** **$\text{NO}_x$  Growth / Decay in the Final Combustion Zone**

Example	Stoichiometric Ratio		$\text{NO}_x$ , ppm dry at 3% $\text{O}_2$ Distance Downstream of the Burner Exit, m		
	(1)	(2)	0	3.7	9.8
25 1	0.47	0.91	226	134	86
2	0.46	0.91	157	-	68
3	0.78	1.31	119	195	183
30 4	0.59	1.26	54	143	132

(1) Second combustion zone (burner exit)

35 (2) First stage of final combustion zone (simulated boiler)

**SUBSTITUTE SHEET**

-11-

As shown in Table 1, Examples 1 and 2 illustrate a process operated in accordance with the present invention. In each of these Examples, the oxygen/fuel stoichiometric ratio in the second (fuel NO<sub>x</sub> control) combustion zone was less than 0.5 and that in the first stage of the final combustion zone was in the preferred range of from 0.8 to 1.0. By contrast, in Examples 3 and 4, combustion in the first stage of the final combustion zone was conducted at an oxygen/fuel stoichiometric ratio of 1.26 and 1.31, respectively.

The concentration of fuel NO<sub>x</sub> at the burner exit was relatively low for each Example (i.e. from 54 to 226 ppm). When the first stage of the final combustion zone was operated fuel-rich (i.e. 0.91 for each of Examples 1 and 2), not only was there no additional (i.e. thermal) NO<sub>x</sub> formed, the total concentration of NO<sub>x</sub> (i.e. fuel and thermal) was reduced further. In contrast, when the first stage of the final combustion zone was operated oxygen-rich (Examples 3 and 4), additional, thermal NO<sub>x</sub> was formed. In the case of Example 4, the concentration of NO<sub>x</sub> in the boiler nearly tripled from that exiting the burner.

**SUBSTITUTE SHEET**

-12-

What is claimed is:

1. A combustion process for a nitrogen-bearing fuel comprising the steps of:

- 5 (a) introducing said fuel into a first combustion zone;
- (b) combusting said fuel in said first combustion zone under a condition of fuel-rich stoichiometry and at a temperature whereby fuel-rich combustion products are produced and undesirable nitrogenous compounds are reduced to low levels;
- 10 (c) passing said combustion products into a two-stage final combustion zone;
- (d) combusting said combustion products in the first stage of said final combustion zone under a condition of fuel-rich stoichiometry and at a temperature of less than about 2200 K; and
- 15 (e) thereafter, combusting said combustion products in the second stage of said final combustion zone at an oxygen/fuel stoichiometric ratio of greater than about 1.0 and at a temperature of less than about 1500 K.

2. The process defined in claim 1, wherein to said first combustion zone is added a finely dispersed particulate material which enhances conversion of undesirable nitrogenous compounds to molecular nitrogen.

20

3. The process defined in claim 2, wherein said particulate material is selected from the group comprising calcium sulphide, calcium oxide, iron sulphide, iron oxide and mixtures thereof.

25

4. The process defined in claim 1, wherein the condition of fuel-rich stoichiometry in the first stage of said final combustion zone comprises an oxygen/fuel stoichiometric ratio of from 0.80 to about 1.0.

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**SUBSTITUTE SHEET**



-13-

5. The process defined in claim 4, wherein the condition of fuel-rich stoichiometry in said first combustion zone comprises an oxygen/fuel stoichiometric ratio of from about 0.45 to about 0.80.

5 6. The process defined in claim 4, wherein the condition of fuel-rich stoichiometry in said first combustion zone comprises an oxygen/fuel stoichiometric ratio of from about 0.55 to about 0.70.

7. The process defined in claim 6, wherein the temperature in said  
10 first combustion zone is in the range of from about 1500 K to about 1800 K.

8. A combustion process for a sulphur- and nitrogen-bearing fuel comprising the steps of:

- (a) introducing said fuel into a first combustion zone;
- 15 (b) combusting said fuel in the presence of a sulphur-capture compound in said first combustion zone under a condition of fuel-rich stoichiometry and at a temperature whereby a combustion mixture is produced including fuel-rich gases, solid sulphur-bearing flyash and slag;
- (c) passing said combustion mixture to a second combustion zone;
- 20 (d) combusting said combustion mixture in said second combustion zone under a condition of fuel-rich stoichiometry and at a temperature whereby fuel-rich combustion products are produced and undesirable nitrogenous compounds are reduced to a low level;
- (e) passing said combustion products into a two-stage final  
25 combustion zone;
- (f) combusting said combustion products in the first stage of said final combustion zone under a condition of fuel-rich stoichiometry and at a temperature of less than about 2200 K; and

**SUBSTITUTE SHEET**

-14-

(g) thereafter, combusting said combustion products in the second stage of said final combustion zone at an oxygen/fuel stoichiometric ratio of greater than about 1.0 and at a temperature of less than about 1500 K.

5 9. The process defined in claim 8, wherein the condition of fuel-rich stoichiometry in the first stage of said final combustion zone comprises an oxygen/fuel stoichiometric ratio of from about 0.80 to about 1.0.

10 10. The process defined in claim 9, wherein the condition of fuel-rich stoichiometry in said first combustion zone comprises an oxygen/fuel stoichiometric ratio of less than about 0.50.

11. The process defined in claim 9, wherein the condition of fuel-rich stoichiometry in said first combustion zone comprises an oxygen/fuel stoichiometric ratio of from about 0.25 to about 0.40.

12. The process defined in claim 10, wherein the condition of fuel-rich stoichiometry in said second combustion zone comprises an oxygen/fuel stoichiometric ratio of from about 0.45 to about 0.80.

20 13. The process defined in claim 11, wherein the condition of fuel-rich stoichiometry in said second combustion zone comprises an oxygen/fuel stoichiometric ratio of from about 0.55 to about 0.70.

25 14. The process defined in claim 11, wherein the temperature in said first combustion zone is in the range of from about 1200 K to about 1600 K.

15. The process defined in claim 13, wherein the temperature in said second combustion zone is in the range of from about 1500 K to about 1800 K.

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**SUBSTITUTE SHEET**

-15-

16. The process defined in claim 8, wherein said sulphur-capture compound is selected from the group comprising oxides, hydroxides and carbonates of calcium, and combinations thereof.

5 17. The process defined in claim 1 or claim 8, wherein said fuel is selected from the group comprising coal, lignite, wood, tar and petroleum products and by-products.

10 18. The process defined in claim 1 or claim 8, wherein said fuel is coal.

19. A coal combustion process comprising the steps of:  
(a) introducing particulate coal into a first combustion zone;  
(b) combusting said coal in the presence of a sulphur-capture  
15 compound in said first combustion zone at an oxygen/fuel stoichiometric ratio of from about 0.25 to about 0.40 and at a temperature in the range of from about 1200 K to about 1600 K, whereby a combustion mixture is produced including fuel-rich gases, slag and solid sulphur-bearing flyash entrained in said gases;

20 (c) passing the combustion mixture to a second combustion zone;  
(d) combusting said combustion mixture in said second combustion zone at an oxygen/fuel stoichiometric ratio of from about 0.55 to about 0.70 and at a temperature in the range of from about 1500 K to about 1800 K, whereby fuel-rich combustion products are produced, such that the  
25 level of undesirable nitrogenous compounds level in said combustion products is reduced to a low level;

(e) separating said slag and a major portion of said flyash from the combustion products;

30 (f) passing the remaining combustion products into a two-stage final combustion zone;

**SUBSTITUTE SHEET**

-16-

(g) combusting said remaining combustion products in the first stage of said final combustion zone at an oxygen/fuel stoichiometric ratio of from about 0.80 to about 1.0 and at a temperature of less than about 2200 K; and

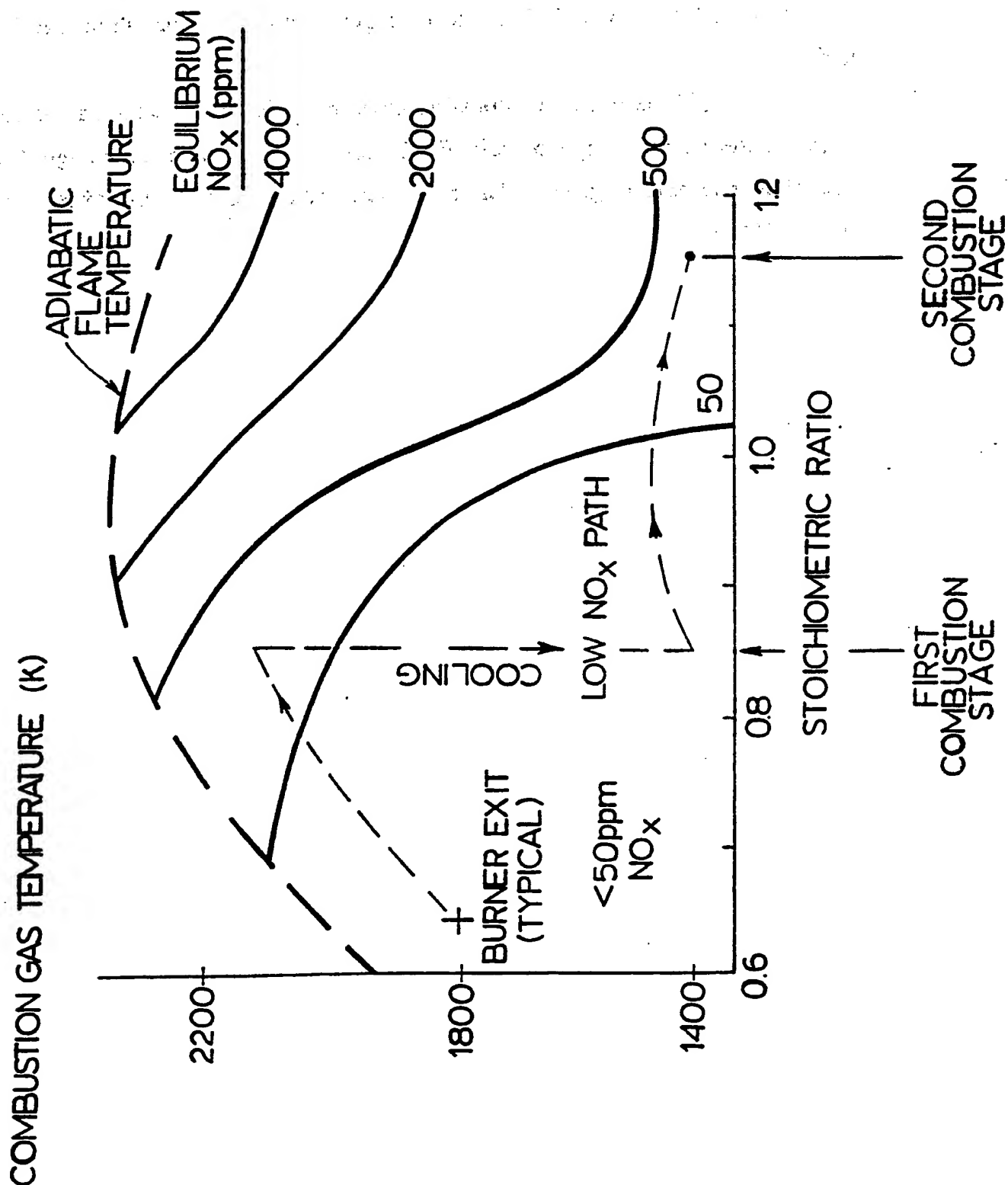
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(h) thereafter, combusting the combustion products from said first stage in the second stage of said final combustion zone at an oxygen/fuel stoichiometric ratio of greater than about 1.0 and at a temperature of less than about 1500 K.

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1/1

FIG.1



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# INTERNATIONAL SEARCH REPORT

International Application No

PCT/CA 91/00004

<b>I. CLASSIFICATION F SUBJECT MATTER</b> (if several classification symbols apply, indicate all) <sup>1</sup> According to International Patent Classification (IPC) or to both National Classification and IPC IPC <sup>5</sup> : F 23 C 6/04, F 23 J 7/00																	
<b>II. FIELDS SEARCHED</b> <div style="text-align: center; border-top: 1px solid black; border-bottom: 1px solid black;">Minimum Documentation Searched<sup>7</sup></div> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 20%; border-bottom: 1px solid black;">Classification System</td> <td style="border-bottom: 1px solid black;">Classification Symbols</td> </tr> <tr> <td style="padding: 5px;">IPC<sup>5</sup></td> <td style="padding: 5px;">F 23 C, F 23 J</td> </tr> </table> <div style="text-align: center; border-top: 1px solid black; border-bottom: 1px solid black;">Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched<sup>8</sup></div>			Classification System	Classification Symbols	IPC <sup>5</sup>	F 23 C, F 23 J											
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IPC <sup>5</sup>	F 23 C, F 23 J																
<b>III. DOCUMENTS CONSIDERED TO BE RELEVANT<sup>9</sup></b> <table style="width: 100%; border-collapse: collapse;"> <tr> <th style="width: 10%; border-bottom: 1px solid black;">Category<sup>10</sup></th> <th style="width: 70%; border-bottom: 1px solid black;">Citation of Document,<sup>11</sup> with indication, where appropriate, of the relevant passages<sup>12</sup></th> <th style="width: 20%; border-bottom: 1px solid black;">Relevant to Claim No.<sup>13</sup></th> </tr> <tr> <td style="text-align: center; vertical-align: top; padding: 5px;">Y</td> <td style="padding: 5px;">US, A, 4500281 (BEARDMORE) 19 February 1985 see column 2, lines 40-68; column 3, lines 1-7, 29-58; column 6, lines 56-68; column 7, lines 1-30; figures 1, 3, 4 ---</td> <td style="text-align: center; vertical-align: top; padding: 5px;">1, 2, 3, 4, 5, 6, 17, 18</td> </tr> <tr> <td style="text-align: center; vertical-align: top; padding: 5px;">Y</td> <td style="padding: 5px;">WO, A, 8906334 (OY TAMPELLA) 13 July 1989 see page 1, lines 5-19; page 3, line 19 - page 4, line 16; page 5, line 27 - page 7, line 27; page 7, line 31 - page 9, line 17; figures 1, 2 ---</td> <td style="text-align: center; vertical-align: top; padding: 5px;">1, 4, 5, 6, 8, 9, 16, 17, 18</td> </tr> <tr> <td style="text-align: center; vertical-align: top; padding: 5px;">Y</td> <td style="padding: 5px;">US, A, 4504211 (BEARDMORE) 12 March 1985 see abstract; column 2, lines 30-39, 60-68; column 3, lines 1-14; column 4, lines 16-66; column 6, lines 10-20; figure 1 ---</td> <td style="text-align: center; vertical-align: top; padding: 5px;">8, 9, 16, 17, 18</td> </tr> <tr> <td style="text-align: center; vertical-align: top; padding: 5px;">A</td> <td style="padding: 5px;">---</td> <td style="text-align: center; vertical-align: top; padding: 5px;">19</td> </tr> </table>			Category <sup>10</sup>	Citation of Document, <sup>11</sup> with indication, where appropriate, of the relevant passages <sup>12</sup>	Relevant to Claim No. <sup>13</sup>	Y	US, A, 4500281 (BEARDMORE) 19 February 1985 see column 2, lines 40-68; column 3, lines 1-7, 29-58; column 6, lines 56-68; column 7, lines 1-30; figures 1, 3, 4 ---	1, 2, 3, 4, 5, 6, 17, 18	Y	WO, A, 8906334 (OY TAMPELLA) 13 July 1989 see page 1, lines 5-19; page 3, line 19 - page 4, line 16; page 5, line 27 - page 7, line 27; page 7, line 31 - page 9, line 17; figures 1, 2 ---	1, 4, 5, 6, 8, 9, 16, 17, 18	Y	US, A, 4504211 (BEARDMORE) 12 March 1985 see abstract; column 2, lines 30-39, 60-68; column 3, lines 1-14; column 4, lines 16-66; column 6, lines 10-20; figure 1 ---	8, 9, 16, 17, 18	A	---	19
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<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p><sup>10</sup> Special categories of cited documents:</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="width: 50%;"> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</p> <p>"G" document member of the same patent family</p> </div> </div>																	
<b>IV. CERTIFICATION</b> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 50%; border-bottom: 1px solid black; padding: 5px;">Date of the Actual Completion of the International Search</td> <td style="width: 50%; border-bottom: 1px solid black; padding: 5px;">Date of Mailing of this International Search Report</td> </tr> <tr> <td style="text-align: center; padding: 5px;">9th April 1991</td> <td style="text-align: center; padding: 5px;">- 3. 05. 91</td> </tr> <tr> <td style="border-bottom: 1px solid black; padding: 5px;">International Searching Authority</td> <td style="border-bottom: 1px solid black; padding: 5px;">Signature of Authorized Officer</td> </tr> <tr> <td style="text-align: center; padding: 5px;">EUROPEAN PATENT OFFICE</td> <td style="text-align: center; padding: 5px;"> <div style="border: 1px solid black; display: inline-block; padding: 2px 10px;">M. PEIS</div> <span style="font-family: cursive; font-size: 1.2em; margin-left: 20px;">M. Peis</span> </td> </tr> </table>			Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report	9th April 1991	- 3. 05. 91	International Searching Authority	Signature of Authorized Officer	EUROPEAN PATENT OFFICE	<div style="border: 1px solid black; display: inline-block; padding: 2px 10px;">M. PEIS</div> <span style="font-family: cursive; font-size: 1.2em; margin-left: 20px;">M. Peis</span>							
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III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category *	Citation of Document, " with indication, where appropriate, of the relevant passages	Relevant to Claim No.
Y	DE, A, 3731475 (DOPCO) 24 March 1988 see page 3, lines 3-18, 38-59 ---	2,3
A	EP, A, 0184846 (ALCOA) 18 June 1986 see abstract; page 6, line 15 - page 7, line 22; page 9, lines 22-26; page 11, lines 6-18; page 12, lines 22-26; page 13, line 26 - page 14, line 25; figure 1 ---	19
A	US, A, 4427362 (DYKEMA) 24 January 1984 cited in the application ---	
A	US, A, 4523532 (MORIARTY) 18 June 1985 cited in the application ---	
A	GB, A, 1508459 (ENERGIAGAZDALKODASI INTEZET) 26 April 1978 ---	
A	GB, A, 2077135 (ACUREX) 16 December 1981 ---	
A	GB, A, 2009375 (EXXON) 13 June 1979 -----	

# ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO.

CA 9100004

SA 43275

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 28/05/91. The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 4500281	19-02-85	None	
WO-A- 8906334	13-07-89	None	
US-A- 4504211	12-03-85	None	
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		NL-A- 7513624	15-06-76
		SE-B- 410802	05-11-79
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		JP-A- 54090625	18-07-79
		NL-A- 7811715	31-05-79
		SE-B- 440393	29-07-85
		SE-A- 7812147	30-05-79

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